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Chapter

Biofuel Development in Sub-Saharan Africa

Olatunde Samuel Dahunsi, Ayoola Shoyombo and Omololu Fagbiele

Abstract

The quest for renewable and sustainable energy generation is fast becoming widespread across Africa due to the understanding that there is a need to seek an alternative to fuels of fossil origin, which currently sustains the largest portion of the world's energy need. Research into the generation of renewable fuels had been on-going in continents like Europe, South America, Asia, and other developed countries bearing in mind the extinction nature of fossil fuels. Globally, attentions are being drawn to fuel generation from biomass and its derivatives such as lignin, triglycerides, cellulose, and hemicelluloses. The aim is to use such fuels for cooking and heating and in vehicles, jet engines, and other applications. Therefore, the integration of the African continent in the race for biofuel production is germane in the quest for survival and developments considering favorable factors like climate, soil, and land mass among other environmental-friendly resources in different African countries.

Keywords: Africa, biogas, biomass, environment, microorganism

1. Introduction

Environmental pollution by solid wastes and lack of access to adequate energy resources are some of the major challenges facing the human populace in Sub Saharan Africa [1–14]. Out of 21 Sub-Saharan African countries, less than 10% have access to energy [15]. Therefore, there is serious need to search for alternative and renewable energy sources from locally available resources in the quest for human survival and national development in the region [15–18]. Besides, there is a need for the adoption of appropriate and economically feasible technologies for the effective management of solid and liquid wastes and energy recovery from them [19, 20].

The global quest for environmentally friendly and ecologically balanced and sustainable energy has been on the increase over the last few decades and this has forced the world to search for other alternate sources of energy [21, 22]. Besides, one of the major tools for national and international development is energy. Developing countries such as Nigeria depend heavily on fuels from fossil origin. There are enormous conventional energy resources (crude oil, tar sands, natural gas and coal) in Sub-Saharan Africa besides the huge amount of renewable/sustainable energy resources including hydro, solar, wind, biomass, etc.

However, the alternative energy sources demand immense economic investment and technical power to operate, and this makes it little difficult for these countries. Presently, energy from biogas is a reliable, abundant, accessible and economically feasible source of alternative and renewable energy which can be generated using agricultural, domestic and industrial materials employing simple technology [23]. The prospect of this technology is bright because it can be utilized to provide energy for households, rural communities, farms, and industries [18].

Biomass such as perennial grasses has been extensively utilized for biofuel production the world over paramount among which are *Panicum virgatum*, *Miscanthus* species, *Phalaris arundinacea* and *Arundo donax* [24]. The use of *Miscanthus* as an energy grass has attracted attention among the perennial C4 grasses since it has been identified as a perfect energy grass and produces maximally when harvested dry. Yields of 3–10 years old plantations grown in two countries in Europe are 113–30 t/ha. This means that if a yield of 20 t/ha could be achieved; it would produce a total energy yield that is equal to 7 t/ha of oil over the life of each harvest. Switch grass has an energy value that is similar to wood yet with minimal water content [25]. After proper investigation of some crops which were perennial grasses, switch grass was observed to produce the highest potential. Other than staying away from the competition between food and fuel crop usage, they are considered to have energy, financial, and ecological advantages over food crops for certain bioenergy products [25]. These grasses possess qualities and prospects as for their utilization and enhancement as lignocellulosic feedstock. In order to meet up to the large demand of biomass supply, an extensive environmental capacity is to be considered which marginal soils are included [26]. Another nutrient rich grass is Napier grass (*Pennisetum purpureum*), a grass that grows in the tropics and can withstand dry conditions. It has 30.9% total carbohydrates, 27% protein, 14.8% lipid 14.8%, and 9.1% fiber (dry weight). Thus, it is cultivated for livestock as energy crops and it is easy to cultivate with a high productivity rate of 87 ton/ha/year [24]. The feasibility of biogas production from Napier grass was observed and was reported that the methane content, yield and production rate were 53%, 122.4 mL CH_4/g TVS remove, 4.8 mL/h at the optimum condition [26].

2. Rationale for biofuel production in Sub-Saharan Africa

The quest for renewable and sustainable energy generation is fast becoming widespread across Sub-Saharan Africa due to the understanding that there is a need to seek an alternative to fuels of fossil origin which currently sustains the world's-energy need. Research into the generation of renewable fuels had been on-going in continents like Europe, South America, Asia and other developed countries bearing in mind the extinction nature of fossil fuels. Globally, attentions are been drawn to fuel generation from biomass and their derivatives such as lignin, triglycerides, cellulose, and hemicelluloses. The aim is to use such fuels for cooking, heating, as fuels in vehicles, jet engines, and other applications. Therefore, the integration of the African continent in the race for biofuel production is germane in the quest for survival and developments considering present and favorable factors like climate, soil, land mass among other environmental-friendly resources in different Sub-Saharan African countries [28]. Africa is the second largest continent in the world after Asia making up 10% of the world's population which is equivalent to about 80% of the population in India sub-continent [29]. As such, biofuels especially biogas, biodiesel, and bioethanol are being considered as the most potent alternatives to fossil fuels in the continental energy mix [30, 31].

3. Various biofuels produced from lignocelluloses

3.1 Biogas

There are two broad processes in biogas development and these are first, the actual production from both edible and non-edible sources and secondly, the compatible technologies for the fuel usage. Nowadays, large scale biofuel projects are gaining considerable attentions and establishment of biogas facilities is fast becoming widespread in the continent while issues of energy security and economic growth are also being discussed in several scientific gatherings [32].

3.2 Biobutanol

This is a second generation biofuel produced as a credible substitute for fossil fuel and usually used as a blend with gasoline. Although butanol is still generated through petrochemical methods, the high demand, depletion rate and price of oil has driven the search for a sustainable source for butanol production. This fuel possess some better attributes which includes higher energy content, lower Reid vapor pressure, easy blending with gasoline at any ratio and ease in transportation when compared to bioethanol [27].

3.3 Bioethanol

This is a first generation biofuel mainly produced via enzymatic fermentation by using yeast to digest biodegradable raw materials with high energy content. Hydrolysis is employed when raw materials such as high energy yielding crops are utilized; this is done to break down the complex nature of the polymer into monomers such as simple sugar followed by conversion of the sugar to alcohol after which distillation and dehydration are used to reach the desired amount that can be utilized directly as fuel [33]. Ethanol can be mixed with petrol if appropriately purified and when utilized in modified spark ignition engines, production of toxic environmental gases will be reduced. A liter of ethanol can yield about three fifths of the energy provided by a liter of gasoline [34].

3.4 Biodiesel

Biodiesel is another example of a first generation biofuel and can be produced directly from vegetable oils and other oleo chemicals via trans-esterification methods or cracking. The possibility of biodiesel replacing fossil fuels as main source for power is one reason for the global research of biodiesel [35]. The trans-esterification procedure may utilize acid, enzymes and alcohol to yield the biodiesel and glycerin as by-product [36]. Oleo chemicals are chemical substances produced from fats and natural oils, they are basically fatty acids and glycerol. Hypothetically, oleo chemicals are better substitute for petrochemicals in terms of sustainability and economic viability [37]. The high price rate of biodiesel is a major constraint to its commercialization in contrast with petroleum, thus the utilization of waste oil should be considered since it is relatively available and cheap [38].

4. Biogas development in Sub-Saharan Africa

Biogas generation via anaerobic digestion is very famous in the Americas, Asia, Europe and India Sub-Continent. However, the Sub-Saharan Africa region has over the last few decades witnessed a very slow acceptance and adoption of this technology despite significant individual, institutional, national and international efforts [21]. This slow pace of development has been linked to scarcity or unavailability of feedstock caused by poor agricultural practices [39]. **Table 1** shows that as at 2005, only a few African countries have adopted the biogas technology with an insignificant number of biogas digesters/plants compared to what is obtainable in other continents [15]. In order to improve this situation, a new African initiative was launched in 2007 in order to install biogas digesters to not less than 2 million households by the year 2020 [30, 31]. By the year 2010, the number of biogas plants in Africa has increased especially in Tanzania with about 4000 digester units [40]. However, only about 60% of these plants were functional while the remaining failed or performed below satisfaction due to reasons like planning and construction errors, poor community awareness, lack of adequate maintenance culture, misconception of the technology's benefits, and lack of technical know-how by end-users among others [40].

Country	Number of small/medium digesters (100 m^3)	Number of large digesters (>100 m^3)	Region
Botswana	>100	1	South
Burkina Faso	>30	—	West
Burundi	>279	—	East
Egypt	>100	<100	North
Ethiopia	>100	>1	East
Ghana	>100	—	West
Cote D'Ivoire	>100	1	West
Kenya	>500	—	East
Lesotho	40	—	South
Malawi	—	1	South
Morocco	>100	—	North
Nigeria	Few	—	West
Rwanda	>100	>100	East
Senegal	>100	—	West
Sudan	>200	—	North
South Africa	>100	>100	South
Swaziland	>100	—	South
Tanzania	>1000	1	East
Tunisia	>40	—	North
Uganda	Few	—	East
Zambia	Few	—	East
Zimbabwe	>100	1	South

Source: Mshandete and Parawira [15].

Table 1.
African countries with biogas producing digesters.

5. The Nigeria scenario

Inadequate energy supply and environmental pollution are some of the challenges being faced in Nigeria and other developing nations. The energy consumption rate of the modern world is an indication that renewable and environmental-friendly energy need be generated from alternative sources. The mono digestion of substrates has been found to be limited in both quantity and quality of generated gas while co-digestion of substrates enhance the anaerobic digestion process as this leads to higher carbon/nitrogen balance and nutrient availability. Biogas research in Nigeria is in its infancy as limited substrates have been utilized and significant effort has not been directed at evaluating the composition and/or succession of the microbes responsible for the bioconversions [41]. As seen in **Table 2**, most of the previous biogas researches utilized animal dung, poultry droppings, peels, human

S/N	Substrate	Average biogas/ methane yield	Digestion type	Digestion scale	Reference
1.	Food waste and human excreta	56.5 L/kg biogas	Anaerobic	Pilot	[38]
2.	Poultry dropping	54 L/kg (biogas): 33.3 L/kg (methane)	Anaerobic	Pilot	[73]
3.	*Cymbopogon citratus* and poultry dropping	39 L/kg (biogas): 25.8 L/kg (methane)	Anaerobic	Pilot	[73]
4.	*Cymbopogon citratus*	28 L/kg (biogas): 21.6 L/kg (methane)	Anaerobic	Pilot	[73]
5.	Rice husks	25.1 L/kg (biogas): 21.3 L/kg (methane)	Anaerobic	Pilot	[74]
6.	Cow dung	61.8 L/kg (biogas): 54.2 L/kg (methane)	Anaerobic	Pilot	[75]
7.	*Tithonia diversifolia*	51.8 L/kg (biogas): 40.2 L/kg (methane)	Anaerobic	Pilot	[67]
8.	*Chromolaena odorata* and poultry dropping	64.8 L/kg (biogas): 56.7 L/kg (methane)	Anaerobic	Pilot	[69]
9.	*Tithonia diversifolia* and poultry dropping	61.8 L/kg (biogas): 54.2 L/kg (methane)	Anaerobic	Pilot	[72]
10.	*Arachis hypogeae*	46.8 L/kg (biogas): 38.9 L/kg (methane)	Anaerobic	Pilot	[70]
11.	*Arachis hypogeae* and poultry manure	59.3 L/kg (biogas): 46.6 L/kg (methane)	Anaerobic	Pilot	[68]
12.	*Carica papaya*	58.4 L/kg (biogas): 45.8 L/kg (methane)	Anaerobic	Pilot	[71]
13.	*Carica papaya* and poultry manure	60.1 L/kg (biogas): 54.3 L/kg (methane)	Anaerobic	Pilot	[65]
14.	*Telfairia occidentalis*	46.4 L/kg (biogas): 32.2 L/kg (methane)	Anaerobic	Pilot	[66]
15.	Banana and plantain peels	49.7 L/kg (biogas): 36.2 L/kg (methane)	Anaerobic	Pilot	[51]
16.	*Panicum maximum* and animal wastes	53.4 L/kg (biogas): 42.4 L/kg (methane)	Anaerobic	Pilot	[76]

Table 2.
Previous substrates used for biogas generation in Nigeria.

excreta, agricultural residues and kitchen wastes as feedstock substrates [41–49]. The use of succulent plants for biogas production has been limited to water lettuce, water hyacinth, cassava leaves, *Cymbopogon citratus* and *Eupatorium odoratum* [41–44, 50, 51]. Besides, the detail analysis of lignocellulosic component and optimization of biogas production processes and parameters are lacking in the Nigerian energy literature.

5.1 Biogas technology adoption in Nigeria

Biogas technology's adoption and operation in Nigeria is still at the infancy stage. This slow pace which is similar to the situation in some other Sub-Saharan African countries is caused by unfavorable government policies, inadequate funding of technology and individual's unwillingness [52]. To this end, several feedstocks which are economically suitable for biogas generation in Nigeria have been selectively identified. These include aquatic plants like water lettuce and water hyacinth; agricultural wastes like cow and piggery dung, poultry droppings and processing waste; industrial wastes like municipal solid wastes and sewage [41–43]. Also, the continuous assessment of other locally available materials for their use in biogas production has been made [44]. The use of succulent plants has been limited to water lettuce, water hyacinth, cassava leaves, *Eupatorium odoratum* and *Cymbopogon citratus* [45, 53]. Similarly, the potential of poultry droppings, cow dung and kitchen/food wastes for biogas generation has been experimented upon [54, 55].

6. Suitable feedstock for biogas generation in Sub-Saharan Africa

One of the major steps in achieving anaerobic digestion success is the careful selection and identification of viable feedstock. The world over, several feedstock have been utilized including food wastes, animal dungs, agricultural and plant residues, wastewaters, Organic Fraction of Municipal Solid Wastes (OFMSW), energy crops, etc. Across Sub-Saharan Africa, substrates suitable for anaerobic digestion include aquatic plants such as water lettuce and water hyacinth; agricultural wastes/residues such as cow and piggery dung, *Cymbopogon citratus*, cassava leaves; municipal wastes such as human excreta, processing wastes, urban refuse and industrial wastes [42–46]. Among these, the potentials of poultry manure, cow dung and kitchen wastes for biogas production have been demonstrated [54–59].

Similarly, Ilori et al. [51] demonstrated the biogas generation from the co-digestion of the peels of banana and plantain and obtained the highest gas volume with an equal mass of both substrates. In another study, the co-digestion of pig waste and cassava peels seeded with wood ash produced a significant increase in biogas yield when compared with the unseeded mixture of the substrates [60]. Fariku and Kidah [61] have also reported the efficient generation of biogas from the anaerobic digestion of *Lophira lanceolata* fruit shells. The biogas producing potentials of Sub-Saharan African local algal biomass has been recognized by Weerasinghe and Naqvi [62]. Odeyemi [50] in his comparative study of four substrates (*Eupatorium odoratum*, water lettuce, water hyacinth and cow dung) as potential substrates for biogas production concluded that *Eupatorium odoratum* was the best while cow dung was the poorest substrate in terms of gas yield. Ahmadu [63] compared the biogas production from cow dung and chicken droppings while Igboro [64] compared the biogas from cow dung from an abattoir and the National Animal Production Institute, Zaria, with the abattoir waste generating the highest volume of gas. Igboro [64] also designed a biogas stove burner which was effectively tested with the biogas produced from cow dung and other feed materials.

Recently, there has been an upsurge in the utilization of many novel materials for biogas generation across Sub-Saharan Africa especially in Nigeria and other countries. These biomasses are found abundantly across the region with very little documentations for use as biofuel feedstock. They include shoots of *Tithonia diversifolia* (Mexican sunflower), and *Chromolaena odorata* (Siam weed). Others are fruit peels of *Carica papaya* (pawpaw), *Telfairia occidentalis* (fluted pumpkin), *Ananas comosus* (pineapple), *Citrullus lanatus* (water melon), *Cucumeropsis mannii* (melon) and the hull or pod of *Arachis hypogaea* (peanut or groundnut), *Theobroma cacao* (Cocoa) and *Kola nitida* (kolanut) [14, 65–72]. Despite the huge availability of these biomasses in their various locations of production, they mostly end up as solid wastes in the environment as little or no usage has been sought for them over the years. Even when some of the biomass has been experimented on for biofuel production, the various arrays of microorganisms involved in their biodegradation are yet to be documented in biofuel literature.

7. Conclusion

Sub-Saharan African region is much blessed with diverse biomass and materials that can be exploited for biofuels generation. It has been seen that biofuels especially biogas technology adoption in the region has been slow thereby requiring more concerted efforts. With the past and anticipated energy challenges attributed to the region due to the overdependence on fossil fuels, the generation of environmental friendly biofuels from the locally available biomass in the region should be given top priority as this will help salvage the menace of energy unavailability and its attendant issues.

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